BRITISH WELDING RESEARCH ASSOCIATION

VOL. 4. FEBRUARY, 1950 No. 1

WELDING RESEARCH

The Journal of the British Welding Research Association

Contents

	Page
Association Notes	1r
Personality Page—Dr. K. Winterton ..	2r
Memorandum on Faults in Arc Welds in Mild and Low Alloy Steels	3r
A Review of Selected Papers on the Flash and Butt Welding of Light Alloys	16r
Publications List, PR.9	21r

PRICE FIVE SHILLINGS

Published by

THE BRITISH WELDING RESEARCH ASSOCIATION · 29 PARK CRESCENT · LONDON · W.1

Welding Research

VOL. 4 FEBRUARY 1950 No. 1

Published by
THE
BRITISH WELDING RESEARCH ASSOCIATION
Head Office and Metallurgical Laboratory
29 Park Crescent, London, W.1
Telephone, Langham 7485
Telegrams, Weldaserch, Wesdo, London.

Research Station
Abington Hall, Cambridge
Telephone and Telegrams, Linton 375

Director of Research, H. G. Taylor, D.Sc.(Eng.), D.I.C., M.I.E.E., F.Inst.P.
Secretary, N. A. W. Le Grand.

Contents

	Page
Association Notes	1r
Personality Page — Dr. K. Winterton	2r
Memorandum on Faults in Arc Welds in Mild and Low Alloy Steels	3r
A Review of Selected Papers on the Flash and Butt Welding of Light Alloys	16r
Publications List, PR 9	21r

Association Notes

Faults in Arc Welds in Mild and Low Alloy Steels

This report defines and illustrates the common faults that can occur in arc welds in mild and low alloy steels. An outline is given of the reasons for their occurrence, and of the ways in which they may be avoided and corrected.

A Review of Selected Papers on the Flash and Butt Welding of Light Alloys

This report gives a resumé of recent published information on the flash and butt welding of light alloys, covers the types of welding machines which are used for the process and considers power and load requirements as well as machine settings. Tables of settings for different materials are included and other sections deal with component clamping, materials and various metallurgical aspects associated with the flash and butt welding of light alloy metals.

"Research and Production" Exhibition

The British Welding Research Association's "Research and Production" Exhibition was opened on Monday, 6th February, by Sir Ben Lockspieser, F.R.S., the Secretary of the Department of Scientific and Industrial Research. The Exhibition which was held at the London Headquarters of B.W.R.A. was a great success. A total of 1,256 individuals visited the Exhibition, amongst which were representatives of over 300 non-member firms, and a total of 179 technical enquiries were recorded, these are being dealt with by the Development and Liaison Department.

New Members

The following new Members have been elected:—

Bruce Peebles & Co. Ltd.,
Eagle Star Insurance Co.,
Metal Propellors Ltd.

Assistant Director Resigns

Mr. W. K. B. Marshall, Assistant Director of the Association, has resigned his position to take up an appointment with one of our Member firms—Messrs. Rockweld Ltd. Mr. Marshall's departure is a great loss to the Association, and he will be missed by all his colleagues on the staff. He takes with him our best wishes in his new appointment.

B.W.R.A. Reports

In future, members of the British Welding Research Association will be entitled to two free copies of all reports issued by the Association, whether confidential or published, and additional copies will be charged for at their respective prices.

The decision to charge in future for the additional copies of duplicated confidential reports is more than compensated by the opportunity of obtaining the additional free copy of published reports.

Personality Page

K. WINTERTON, Ph.D.

Kenneth Winterton, who is the Senior Metallurgist of the B.W.R.A., was born at Edgbaston, Birmingham, in 1919, and was educated at the George Dixon Secondary School, where he won a University Entrance Scholarship to Birmingham University. In 1940 he graduated with a First Class Honours Degree, and started post-graduate work as a Boxen Scholar of Metallurgy. This involved joining a team of investigators working on problems connected with the welding of high tensile alloy steel under the general auspices of the Ministry of Supply. The work required metallurgical researches on alloy steels and the testing and development of what were then new welding methods. On these investigations he was awarded a Ph.D. degree in metallurgy in 1943.

Dr. Winterton then joined the Tin Research Institute where he was engaged on work sponsored by the Ministry of Supply on the founding of copper base alloys. This work consisted of the development and extension of new casting methods in various alloys, and included experimental investigations and routine testing. The improved methods of fabrication which were devised, were regarded as of great value and during the war years, Dr. Winterton played a large part in encouraging various firms to adopt the new methods.

In 1946 he left the Tin Research Institute to take up an appointment as a Research Metallurgist with B.W.R.A. His work at the outset was primarily concerned with problems of steel welding and later with various metallurgical researches on light alloys. In 1949 he was promoted to the post of Senior Metallurgist in succession to Mr. J. G. Ball.

He is the author of a great many papers which have been published in Scientific Journals, and is author or part author of many of the confidential reports which have been issued by the Association, his latest being "Tensile Properties of Mild Steel Weld Metal at High Temperatures."

In lighter moods and for relaxation he plays all-the-year-round tennis, and chess, of which he is an exponent of considerable ability. He has won several cups and trophies, at tournaments in Blackpool, Plymouth and Birmingham. In this, as in everything else he does, he shows that quiet persistence which is the keynote of all his work.

R.53

Faults in Arc Welds in Mild and Low Alloy Steels

This Report was first issued to members of the British Welding Research Association in October, 1949, as a confidential document.

I. INTRODUCTION

In this memorandum typical faults which can occur in arc welds in mild and low alloy structural steel construction are defined and illustrated; an outline is given of the reasons for their occurrence, and of the ways in which they may be avoided and corrected.

To assist Engineers, Inspectors and Welding Supervisors in making reference to a particular detail, each weld fault is dealt with under the following common sub-headings: Description; Cause and Prevention; Effect on Strength; Correction.

It should, of course, be a first aim in the fabrication of welded constructions to produce welds which are entirely free from faults, or at least from significant faults. To this end the most careful control at all stages of the work is essential. Such control should commence in the design and drawing office, where it should be stressed that designs and details must be arranged so that the welds can be deposited properly.

All joints should be readily accessible to the operator, and the construction and assembly of the unit should in general permit the welds to be made in the downhand position. Full information as regards weld sizes and details, plate preparation, assembly and fit-up, welding procedure, sequence and so on should be given on the drawings, or by separate charts or other suitable means, to ensure that the works staff is fully conversant with the requirements of the drawing office, and of the planning or production departments.

During fabrication, all welding should be carried out under constant supervision, by welding operators trained and tested to weld under conditions and on the type of welds appropriate to the class of work on which they are employed.

It is advisable that identification and record systems be used by which responsibility for the execution and supervision of welding can be established at any time during or following completion of the work.

The nature of inspection will depend on the class of work and the special value of radiographic and other non-destructive methods of examination, where justified, should be noted.

Welding equipment should be of adequate capacity for the job and the plant should be maintained in a clean and efficient condition. Electrodes should be of good quality and of type appropriate to the work; suitable arrangements should be made for storing them in a dry atmosphere.

Having taken all general precautions of this kind, however, there remains the factor of human fallibility, and occasionally faults will occur in welded joints. It is the purpose of this memorandum to outline the cause, significance, prevention and correction of the main faults, and to assist thereby in promoting a high standard of arc welding throughout industry.

II. WELD DETAILS

The following diagrams illustrate the terms used to describe particular features of fillet welds and butt welds:—

III. DEFINITIONS AND DETAILS OF WELD FAULTS

(i) *Incomplete Penetration*

Definition: A gap left by failure of the weld metal to fill the root.

Description

Incomplete penetration defines a condition where the weld metal fails to reach the root of a joint, or fails to fuse completely with the root faces of the parent plate. As a result voids or slag inclusions may exist at the root zone of the weld.

Cause and Prevention

Effective penetration depends upon the use of the correct electrode size in relation to the form of the joint, the correct welding current; and, in the case of butt welds, suitable joint preparation allowing proper manipulation of the electrode. Accuracy of joint preparation and fit-up are most important and should be as specified.*

It may be necessary, in order to obtain complete penetration in butt welds welded from both sides, to chip out or flame gouge the back of the first run before depositing the root or sealing run on the opposite side of the joint. The groove formed at the back of the joint should expose the sound metal of the first run and should allow effective manipulation of the electrode and full penetration of the weld metal. To avoid undue chipping or gouging, the root faces and root gap of prepared butt joints should be maintained within recommended limits. Figs. 1 to 5 illustrate incomplete penetration in butt welds.

In fillet welds the use of insufficient welding current, or too large an electrode, may result in lack of penetration at the root (see Fig. 6). The use of a small electrode does not lead necessarily to improved penetration, however, and the largest size of electrode, consistent with ease of manipulation and heat capacity of the work should always be used.

Slag inclusions and cracking are frequently associated with poor penetration in the root zone of fillet welds (see Fig. 27). In extreme cases the use of very low welding current may result in a large void being formed by the weld metal bridging the fusion faces.

In general, wherever practicable, fillet welds should be made in the downhand position. Welding manipulators or other positioning devices may be used with advantage.†

Where automatic welding is used care must be taken to set the machine accurately to follow the line of the joint, otherwise lack of penetration may occur due to the welds being offset. (Fig. 7.)

Effect on Strength

Incomplete penetration causes local stress concentrations to be set up at the root of a weld, and, under pulsating or fluctuating loads, the fatigue endurance of the joint will generally be seriously affected.

Correction

Lack of penetration can only be rectified by removing completely the defective portions of the welded seam and rewelding. Care should be taken that the recess, formed by removing the defective metal, allows adequate manipulation of the electrode and full penetration of weld metal. The surrounding surfaces should be properly cleaned before rewelding.

(ii) *Lack of Fusion*

Definition: A discontinuity in a weld between weld metal and parent metal, or between parent metal and parent metal or between weld metal and weld metal.

Description

Lack of fusion denotes a condition where boundaries of unfused metal exist, either between the parent metal and weld metal, or between adjacent layers of weld metal, and the term should not be confused with lack of penetration. Fig. 8 shows lack of fusion between weld metal and parent metal in an open square butt weld.

* See Memorandum T.15, "Recommended Technique for making Butt-Welds in Mild Steel Plating." Issued November, 1945, by the B.W.R.A. See also B.S.538 (1940).

† See Memorandum T.13A, "Recommended Technique for making Fillet Welds in the Downhand, Vertical and Overhead Positions." Issued March, 1945, by the B.W.R.A.

Cause and Prevention

Imperfect fusion results mainly from the presence of foreign matter, such as slag, oxides, scale or other non-metallic substances which prevent the underlying metal from reaching fusion temperature, and the fault can normally be avoided by ensuring that the joint is perfectly clean. In the case of multi-run welds careful attention should be given to the deslagging of welds between the deposition of successive runs.

If individual runs are badly placed, or the surfaces are rough and provide a hindrance to thorough deslagging, they should be chipped or ground before the deposition of further weld metal.

The use of the correct welding current is important in securing complete fusion of the weld metal and parent metal. Too low a current frequently results in lack of fusion and the fault may also arise if an excessively high current is used. In the latter case the rate of melting of the electrode tends to induce the operator to employ an excessive welding speed with the result that the weld metal is deposited upon underlying metal that has not been heated sufficiently to reach fusion temperature.

Effect on Strength

Lack of fusion tends to reduce considerably the strength of a joint subjected even to static loading. In a joint subjected to pulsating or fluctuating loads it is particularly serious.

Correction

Lack of fusion can only be rectified by removing completely the defective portions of the welded seam, and rewelding. Care should be taken that the recess, formed by removing the defective metal, allows adequate manipulation of the electrode and full penetration of weld metal. The surrounding surfaces should be properly cleaned before rewelding.

(iii) *Undercut* Definition: A groove or channel in the parent metal along a toe of a weld.

Description

The term "undercut" applies to the condition where a local reduction in section of the parent plate occurs alongside the weld deposit. The fault generally appears as a groove, either continuous or discontinuous. This condition may occur either on the surface of the parent plate at the toes of weld, or in the fusion faces of multi-run welds. (See Figs. 9 to 13.)

Cause and Prevention

Undercutting is most commonly associated with the use of excessive welding current, but it is also caused frequently by the operator using an incorrect technique such as too rapid a welding speed, excessive side manipulation or wrong angle of electrode. In certain circumstances the fault may, however, be due to the inherent welding characteristics of the electrode. Undercutting is also sometimes associated with the presence of heavy mill-scale on the surface of the parent metal.

Effect on Strength

In the case of pulsating or fluctuating loading the presence of even slight undercutting will reduce the fatigue endurance of the joint and the fault should not be permitted. In the case of static loading, however, the presence of very small and intermittent undercutting may usually be disregarded.

Correction

The fault may be rectified by adding further weld metal to the weld seam at the point where undercutting occurs. Deep undercutting should be chipped away before rewelding, particularly if it contains slag, as this is likely to prevent complete fusion of the underlying metal. The additional weld metal deposited should conform in shape as nearly as possible to the general contour of the desired weld.

In correcting this fault in high-tensile steels care should be taken that the welding procedure used corresponds to the recommended procedure for the particular steel under repair.

(iv) *Edge of Plate Melted Off.*

Definition: An imperfection in a lap weld due to a free edge of a plate being melted off.

Description

This fault is a particular case of incorrect weld size and sometimes profile (see page 10) and applies to the condition where in depositing a fillet weld in a lap or strap joint, the exposed corner of the parent plate is melted away along the length of the weld, resulting in a reduction of the thickness of the plate at the edge. (Figs. 14 to 16.)

Cause and Prevention

The fault may be caused by incorrect manipulation of the electrode, insufficient lap, or by using an electrode that is too large in relation to the parent plate thickness.

Where a fillet weld is applied to the square edge of a part the designer should arrange, where possible, that the size of the weld is at least one-sixteenth inch less than the edge thickness in order to avoid melting the exposed corner.

Effect on Strength

The static and fatigue strength of a welded lap or strap joint will be reduced where this fault occurs inasmuch as the apparent throat of the weld may be regarded, incorrectly, as equivalent to the throat of a weld equal in size to the plate thickness. The actual throat will, in effect, be reduced by the melting of the corner of the plate, and this is illustrated in Fig. 15.

Correction

The fault can be rectified by depositing additional runs of weld metal and restoring the throat thickness to the correct size. The method of correction is illustrated in Fig. 17.

(v) *Overlap*

Definition: An imperfection at a toe of a weld caused by an overflow of weld metal on to the surface of the parent plate without fusing to the latter.

Description

Overlap defines a condition where an excess of weld metal extends beyond the limits of fusion at the surface of the plate. This condition may exist at isolated points or it may occur continuously along the welded joint. It is more often associated with fillet welds and results in the apparent increase in the size of the fillet weld. Fig. 18 shows overlap in a fillet weld and Fig. 19 overlap in a butt weld.

Cause and Prevention

The fault arises, frequently, from an incorrect manipulation of the electrode. In flat or horizontal-vertical welding the use of a wrong electrode angle which allows the weld metal to flow away from the fusion zone, or the use of too large an electrode in relation to the position of welding should be avoided. The correct welding current and arc length should be used. The use of excessive current may give rise to overlap due to the increased melting rate of the last portion of the electrode.

The welding speed employed should give adequate fusion at the toes of a weld. Too low a welding speed may result in the weld metal flowing beyond the fusion zone, and should be avoided.

Single run fillet welds, larger than $\frac{5}{16}$ inch in leg length and made in the horizontal-vertical position, tend to sag towards the base and cause overlapping at the toe of the horizontal leg. For welds of such size more than one run is generally required, the exact number depending on the type of electrode and welding technique used.

Effect on Strength

Structural discontinuities of this kind at the toes of a weld will act as stress raisers and may lead to early failure of the joint under pulsating or fluctuating loads. Under such conditions of loading the fault should not be permitted. In statically loaded joints the effect of overlap may not be serious except in regard to the effect on the size of fillet welds.

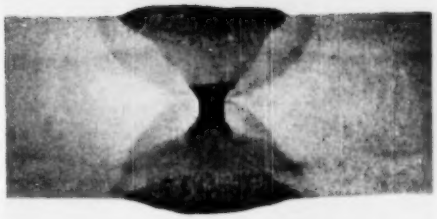


Fig. 1. Incomplete penetration in a double vee butt weld due to faulty welding procedure and incomplete cleaning of slag.

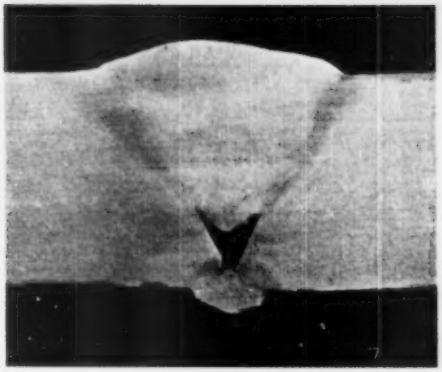


Fig. 2. Incomplete penetration in a single vee butt weld due to use of too large an electrode or too low welding current.

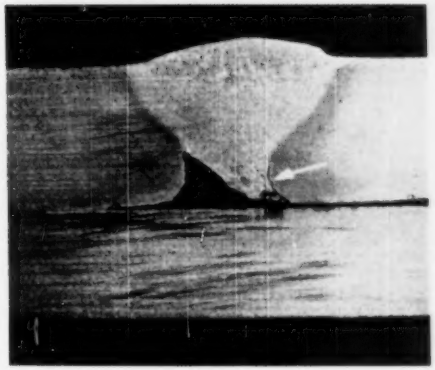


Fig. 3. Incomplete penetration in an open square butt weld with backing bar due to gap being too narrow, or, conversely, electrode too large (arrow also indicates lack of fusion).

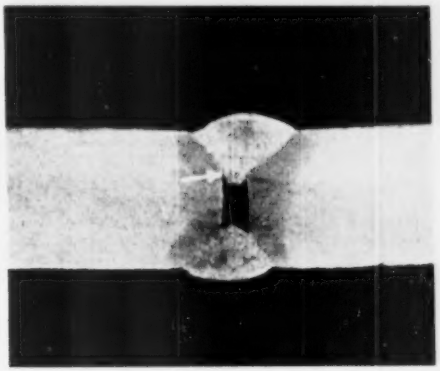


Fig. 4. Incomplete penetration in an open square butt weld due to gap being too narrow; alternatively, use of wrong type of electrode, or too low a current, or speed too fast (arrow also shows lack of fusion, i.e. too long a run length).

Fig. 5. Incomplete penetration in a close butt weld.

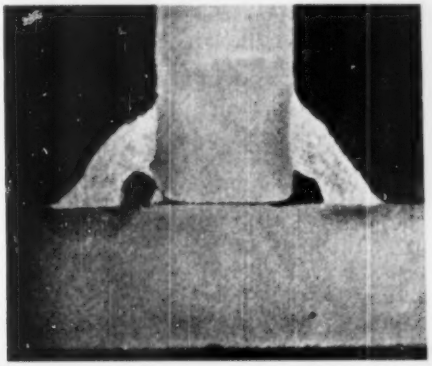


Fig. 6. Incomplete penetration in horizontal-vertical fillet welds. (See also Fig. 27.)

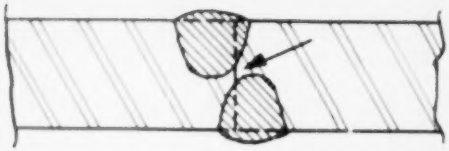


Fig. 7. Incomplete penetration in a butt weld made by the automatic process due to welds being offset from centre of joint.

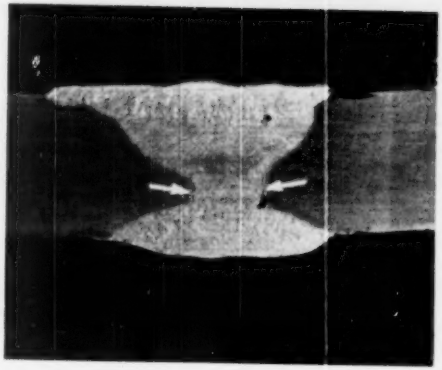


Fig. 8. Lack of fusion between weld metal and parent metal in an open square butt weld. (See also Figs. 3 and 4.)

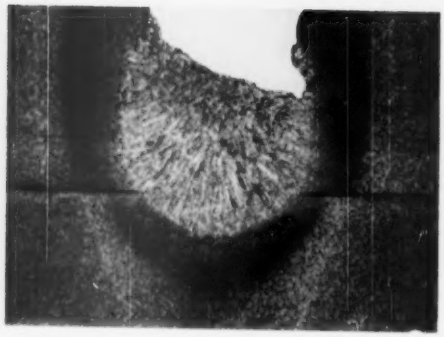


Fig. 9. Undercut at the side of a butt weld made on backing bar. This may cause void or slag inclusion in next run.

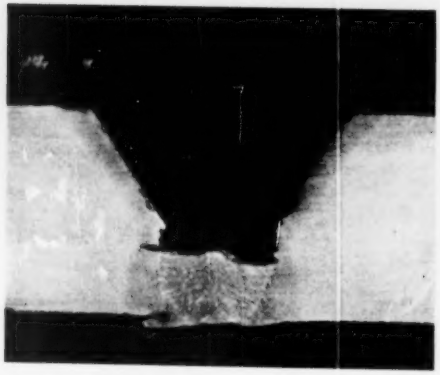


Fig. 10. Undercut in the first run of a vee butt weld.

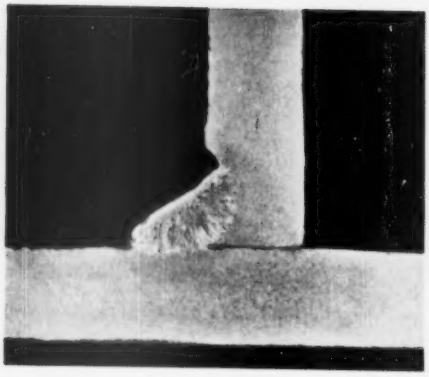


Fig. 11. Undercut in the vertical leg of a horizontal-vertical fillet weld.

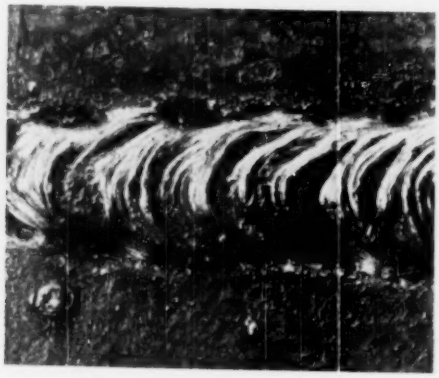


Fig. 12. Undercut at the toes of a butt weld.

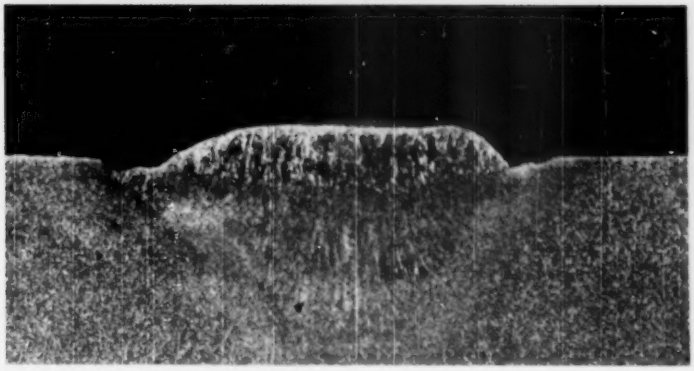


Fig. 13. Section of vee butt weld shown in Fig. 12, illustrating reduction of plate edge due to undercutting at the toes of the weld.

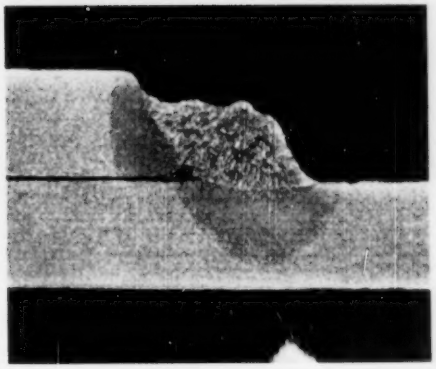


Fig. 14. Edge of plate melted off in a lap joint resulting in reduction in weld size.

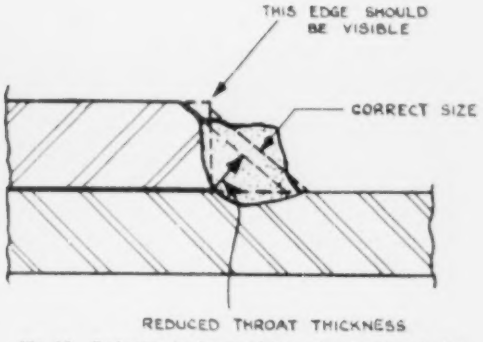


Fig. 15. Reduction in throat thickness due to edge of plate melted off.

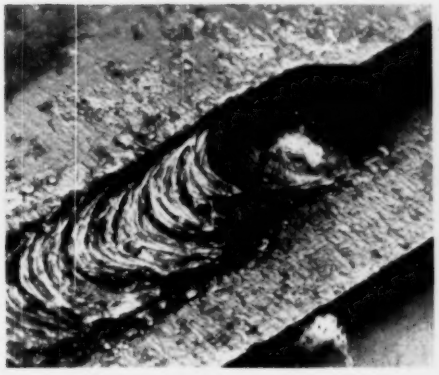


Fig. 16. Edge of plate melted off in a lap joint caused by incorrect manipulation of the electrode, or use of too large an electrode.

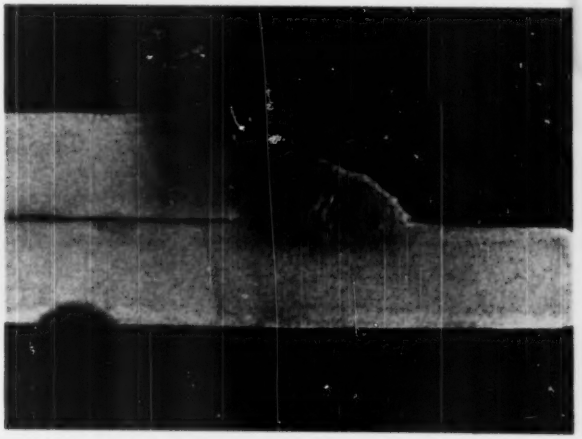


Fig. 17.—Method of correcting edge of plate melted off, by depositing weld metal to restore correct weld size.

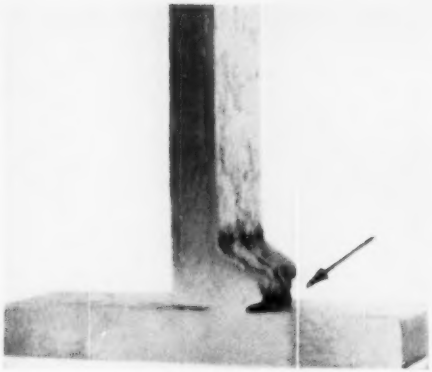


Fig. 18. Overlap in a horizontal-vertical fillet weld.

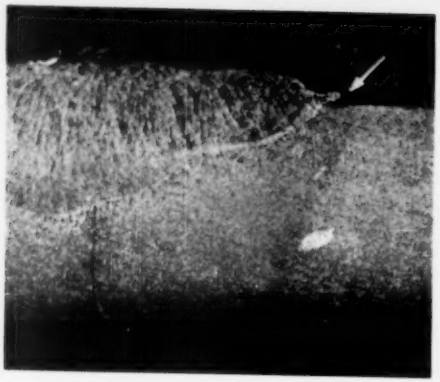


Fig. 19. Overlap at the toe of a close square butt weld.

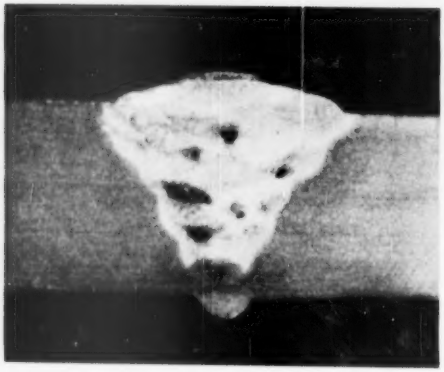


Fig. 20. Slag inclusions in a single vee butt weld due to incomplete cleaning of slag between runs.

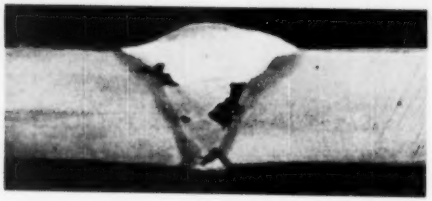


Fig. 21. Slag inclusions at the root and fusion faces of a single vee butt weld.

Fig. 22. Excessive slag inclusions in a section of weld metal.

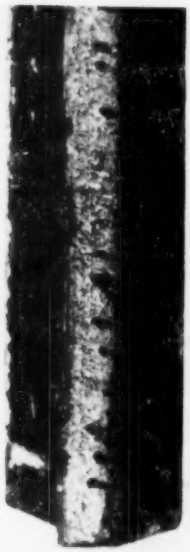


Fig. 23. Piping (worm holes) at root of fillet weld. Probably due to use of too large an electrode (3/8") for first run on plate having heavy scale and containing non-metallic inclusions.

Correction

Overlap can usually be rectified by removing the excess weld metal. Care should be taken to leave a smooth surface and to avoid forming deep grinding marks in the weld or parent metal.

(vi) *Slag Inclusion*

Definition: Slag or other foreign matter entrapped in weld.

Description

The term "slag inclusion" refers to any non-metallic matter that may be included in the weld. In the metal arc process the usual source of inclusion is the slag formed by the electrode covering. Figs. 20, 21 and 22 show sections of welded joints and weld metal containing slag inclusions.

Cause and Prevention

Slag may be forced into the weld metal by the arc during the welding operation, in which case it will generally be finely dispersed throughout the weld; or it may be trapped in cavities such as are formed by undercutting or uneven preceding runs. In the latter case the inclusions are likely to appear as an elongated line of included slag, which may be continuous or discontinuous. In multi-run welds inclusions frequently occur as a result of imperfect cleaning of the slag between the deposition of successive runs, and, in this respect, the shape and surface condition of the preceding runs are important. (Fig. 21.)

Although the slag formed by the electrode covering is the chief source of inclusions in a weld, other non-metallic matter may be included if the fusion faces or surrounding parent plate surfaces are not sufficiently clean.

Heavy mill scale, loose rust, dirt and grit, and other substances which might affect the quality of the weld should be removed prior to welding. A slight layer of rust, light oxide film resulting from gas cutting, or coating of linseed oil, may usually be disregarded.

Care should be taken in preparing fusion faces to leave the surface reasonably smooth and free from irregularities such as would interfere with the deposition of the weld or be the cause of slag pockets or voids. Where hand gas cutting is employed the cutter should be adequately guided to ensure a smooth edge.

The welding characteristics of the electrode constitute an important factor in relation to inclusions, particularly the viscosity of the slag which affects the ease of control during welding. The molten slag should float freely to the surface of the metal and be easily removable after solidification.

Slag removal can generally be accomplished by wire brushing and light chipping. If, however, the weld surface is irregular, or excessively convex, it may be necessary to chip the weld to a smooth surface, before depositing additional runs.

Slag inclusions are often associated with lack of penetration, and in this respect full consideration should be given to those factors that are likely to cause poor penetration, i.e. the use of too large an electrode; an inadequate welding groove angle; oversize root faces, incorrect angle of electrode, etc.

For lower runs in a butt weld groove the electrode and its manipulation should be such as to give a deposit with a uniformly flat or slightly concave surface.

Effect on Strength

The strength of a welded joint may be considerably reduced if large irregular inclusions, or elongated lines of inclusions at the weld junction are present. These sometimes give rise to radiating hair line cracks (see Fig. 30). The presence of small, isolated, globular inclusions may not, however, seriously affect the static strength of a joint and these may be normally be disregarded.

Correction

To rectify welds containing slag inclusions the defective portions should be removed and the joint rewelded where necessary. Care should be taken that the recess, formed by removing the defective metal, allows adequate manipulation of the electrode and full penetration of weld metal. The surrounding surfaces should be properly cleaned before rewelding.

(vii) *Porosity*

Definition: A group of gas pores in a weld.

(a) Piping (Wormhole)

Definition: An elongated or tubular cavity due to entrapped gas.

(b) Blowhole

Definition: A large isolated cavity due to entrapped gas.

Description

The term "porosity" refers to the presence of cavities in the weld metal, caused by the entrapment of gas. In general, porosity takes the form of small spherical cavities, either scattered throughout the weld or clustered in local regions. (See Fig. 24.)

In some cases elongated or tubular gas cavities (referred to as "Piping"), or large, round, isolated gas cavities (referred to as "Blowholes"), may be present in the weld. These may be partially filled with slag. (Fig. 23 shows "piping" in a fillet weld.)

Cause and Prevention

The formation of porosity is due to the entrapment of gas evolved by chemical reaction during the welding process. A number of factors contribute to the occurrence of this fault. The composition of the parent plate and electrode core wire is important, particularly with regard to sulphur content. High sulphur readily promotes the formation of porosity; an example of this is shown in Fig. 33. Excessive moisture content of the electrode covering will also give rise to this fault and it is most important to ensure that stored electrodes are maintained in a dry condition. If electrodes become affected by dampness, but are not otherwise damaged, they should only be used after being dried out in a manner approved by the manufacturers.

The use of low welding current, too long or too short arc lengths, or any other factor which promotes rapid freezing of the weld metal will tend to produce porosity. It is sometimes advisable to increase the solidification period by using a higher current, or by "puddling" the weld metal, in order to allow sufficient time for the gases in solution in the weld metal to escape.

Attention should also be given to the condition of the fusion faces which should be free from moisture, mill scale or any other material likely to affect the quality of the weld.

Effect on Strength

If the effective load carrying area of a welded joint is reduced, or serious stress raisers introduced, by the presence of excessive porosity, blowholes or piping, then the mechanical properties are likely to be considerably impaired. This is particularly the case where the applied stress is of a fatigue producing nature. The static strength of a joint may not, however, be affected to any great extent by the presence of small, finely dispersed porosity.

Correction

Welds containing excessive porosity should be rectified by the removal of the defective portions of the seam, and rewelding. Care should be taken that the recess, formed by removing the defective metal, allows adequate manipulation of the electrode and full penetration of weld metal. The surrounding surfaces should be properly cleaned before rewelding.

(viii) *Crack*

Definition: A discontinuity produced either by tearing of the metal while in a plastic condition (hot crack), or by fracture when cold (cold crack).

Description

Cracks in fusion welded joints may occur in either the weld metal or parent metal. Weld metal cracks may generally be classified as longitudinal, transverse, crater, and "hairline" cracks which generally are associated with slag inclusions. Longitudinal cracks in a weld seam may occur as an extension of crater cracks.

Parent metal cracks are situated, normally, within the heat affected zone of the material and may be either longitudinal (adjacent to the edge of a weld seam), transverse, or under-run.* Transverse cracks in parent metal frequently originate from cracks in the weld.

* *Note.*—Under-run cracking is sometimes referred to as "under bead" cracking. The term "under bead" is used more correctly, however, to define excess metal protruding through the root of a fusion butt weld.

Cause and Prevention

(a) Weld metal cracks

Weld metal cracks are caused by high localised stresses in the joint arising from the shrinkage of the weld metal and the resistance to movement of the parts during welding. It is therefore necessary to give careful consideration to the joint conditions and the degree of restraint opposing movement of the parts caused by weld shrinkage. The order of assembly should be such as to allow shrinkage to take place freely as far as possible.

The size of individual runs should be large enough to withstand shrinkage stresses. This is particularly important in the welding of heavy plates and sections or in conditions of restraint. Rapid cooling of the weld metal by chilling agents (i.e. draughts, low temperature conditions) increases the tendency to cracking.

Badly fitted parts, or incorrectly prepared joints, frequently result in poorly fused areas, lack of penetration, or slag inclusions in a weld, and hair-line cracks may be initiated from these defects and progress throughout the depth of the weld. (See Figs. 26, 27 and 30.)

Longitudinal weld metal cracks are more likely to occur in the first layer of a weld than elsewhere (Fig. 28) and, if not cut out and rewelded they may spread through subsequent layers of weld metal. Cracks of this nature frequently result from unsatisfactory shape or position of the deposit and in such cases it may be necessary to change the welding procedure. Longitudinal cracks may also occur as an extension of crater cracks, and for this reason all weld runs should be completed in such a manner as to avoid leaving a deep crater.

Transverse weld metal cracks are generally associated with joints having a high degree of restraint and, may extend into the parent plate, particularly if the heat-affected zone has hardened to any extent during welding. Hardness and brittleness of the heat-affected zone are factors of prime importance in the problem of cracking, particularly in the case of high tensile steels, and they are discussed more fully in the following section on parent metal cracking.

In certain circumstances it may be desirable to use special mild steel or austenitic welding electrodes which deposit weld metal highly resistant to cracking. An account of the use of these electrodes is contained in Memorandum T.2* dealing with the arc welding of high tensile, low alloy, structural steels.

The sulphur content of most commercial mild steels does not normally affect the weldability of the material. Weld metal cracking may be encountered, however, if excess sulphur is present in the parent plate or electrode core wire (Fig. 33). Where this is suspected it may be conveniently revealed by taking sulphur prints. Fig. 34 shows sulphur prints of steel studs containing excess sulphur as compared with normal quality material. Although sulphur is probably the most common objectionable element in mild steel from the point of view of good weldability, other elements, including nickel, may occur as impurities and may lead to cracking if excessive amounts are present.

In the case of automatic welding where the crater produced is of considerable size, it is generally necessary to arrange extension plates at the ends of butt welds so that the machine starts and finishes its run clear of the joint. The starting and finishing plates should be the same thickness as the joint material, and of the following minimum dimensions:—

> Starting plates 6 in. wide by 6 in. long in direction of seam.
> Finishing plates 6 in. wide by 9 in. long in direction of seam.

The effect of submerged arc and similar welding is to open up the seam ahead of the arc and it is therefore necessary for the finishing plates to be butt welded to the workpiece at the end of the joint for their full width and thickness to prevent the seam from opening in this manner. Experience has shown that unless these welds are fully effective, cracking is likely to occur in the seam welds.

* Memorandum T.2. "The Arc Welding of High Tensile (Low Alloy) Structural Steels." Revised Edition. Issued February, 1944, by the B.W.R.A.

(b) Parent metal cracking

Although parent metal cracking may occur under certain conditions in thick sections of mild steel it is more particularly associated with high-tensile steels (i.e. medium carbon, low alloy and high alloy steels). Parent metal cracks in high tensile steels are normally situated within the heat-affected and hardened zone of the material and are attributable to the effects of the composition of the parent plate, the associated cooling rate after welding and the degree of restraint. A number of factors influence the cooling rate such as the thickness of the parent plate, the rate of heat input during welding and the atmospheric temperature.

The hardenability of the various high-tensile steels differs considerably according to the composition of the material, and the following remarks, whilst holding good to a certain extent for most high tensile steels, are intended primarily to apply to low alloy structural steels: they should also be considered, however, in dealing with thick sections of mild steel.

The hardening of the heat affected zone results from the rapid cooling of the metal after deposition of the weld metal and this hardness increases with the thickness of the plate, due to the quicker dissipation of heat and consequently more sudden cooling. The danger of cracking therefore increases with plate thickness, particularly in joints that are highly restrained. The rate of cooling should be retarded sufficiently to avoid the formation of an excessively brittle zone at the weld junction, and reduce the rate at which shrinkage stresses are developed.

Reduction of the cooling rate can be achieved either by pre-heating, immediate post-heating, or by increasing the rate of heat-input per unit of weld by means of suitable procedure. A suitable procedure is the deposition of large runs by the use of relatively large electrodes or by vertical upwards welding.

Multi-run welds should be so deposited that the heat is maintained in the surrounding plate, and succeeding runs should be made as soon as possible after the first run. This procedure is usually known as "block" welding.

In the welding of steels liable to harden, the use of small tack welds must be avoided if pre-heating cannot be applied. Similarly the striking of arcs on the parent plate outside a weld groove should be carefully guarded against, as local hard spots may result and give rise to the formation of small surface cracks.

Some form of low temperature pre-heating is also recommended in mild steel structural work if the atmospheric temperature is at, or below freezing point. For parts above 1½ in. in thickness it is advisable to take the chill off the plate prior to welding even for temperatures slightly above freezing point. The use of special electrodes, referred to in the preceding section, may be of advantage under certain conditions.

Effect on Strength

The strength of a welded joint will, under any conditions of loading, be very seriously reduced by the presence of cracks in a weld and under no circumstances should the fault be permitted.

Correction

Weld metal or parent metal containing cracks can only be rectified by removing the defective parts and by rewelding. Precautions should be taken to ensure that the cracked portions are removed completely. The metal removed should preferably extend well beyond the visible extremities of the cracks and the surrounding surfaces should be properly cleaned before rewelding. Attention is drawn to the fact that a modified welding procedure may be necessary to prevent a recurrence of the fault.

(ix) *Incorrect Weld Size and Profile*

> Definition. A departure of the shape and or size of weld otherwise correctly formed, from that specified.

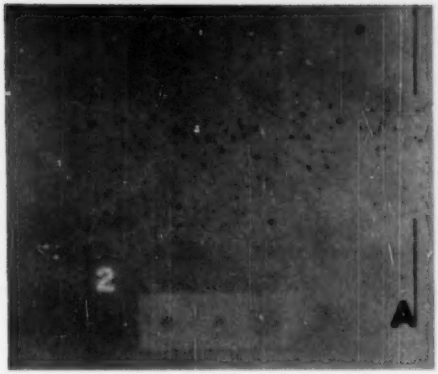


Fig. 24. Radiograph of butt weld showing excessive porosity.

Fig. 25. Macro-section of butt weld shown in Fig. 24.

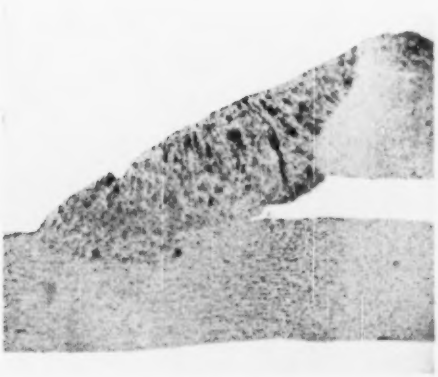


Fig. 26. Section of lap weld showing weld metal crack and incomplete penetration due to faulty fit up.

Fig. 27. Crack in throat of fillet weld due to lack of root penetration.

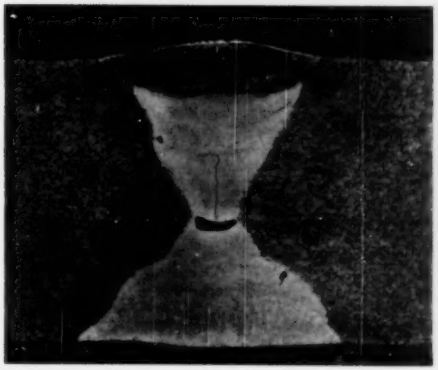


Fig. 28. Weld metal crack in first run of a double vee butt joint.

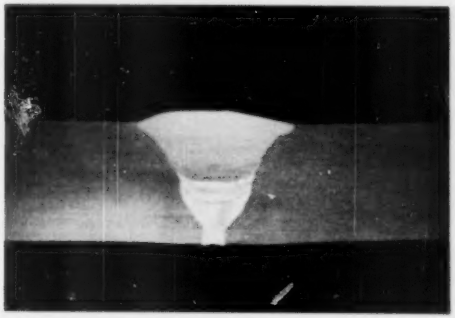
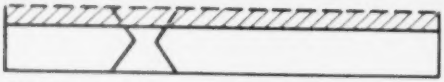


Fig. 29. Under-run cracking in weld metal in a single vee butt joint.



Double vee butt weld. Material shown shaded removed to reveal section of weld parallel to plate face. (See below.)

Fig. 30. Horizontal section through the weld showing internal cracking associated with irregularly shaped slag pockets.

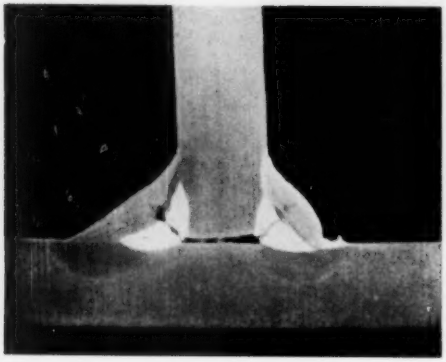


Fig. 31. Longitudinal and under-run cracking in horizontal-vertical fillet welds.

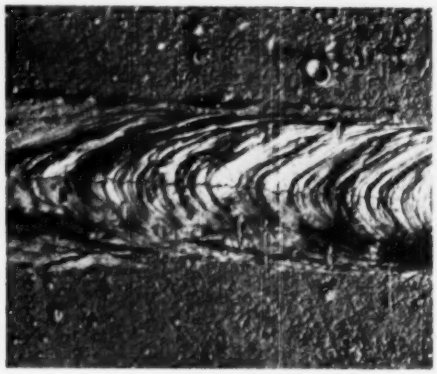


Fig. 32.—Longitudinal weld metal crack in a butt weld.

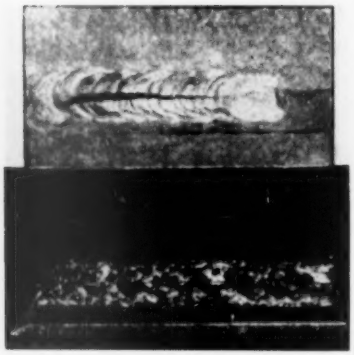


Fig. 33. Hot crack and porosity due to sulphur.

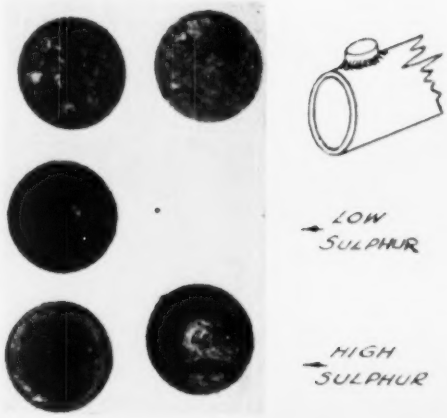


Fig. 34. Sulphur prints of mild steel studs containing low and high sulphur.

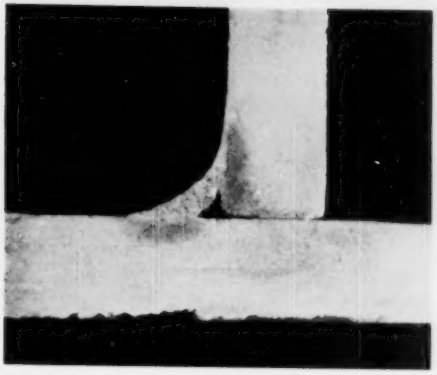


Fig. 35. Horizontal-vertical fillet weld. Excessive concavity, lack of root penetration, and slag inclusion, due to excessive weaving.

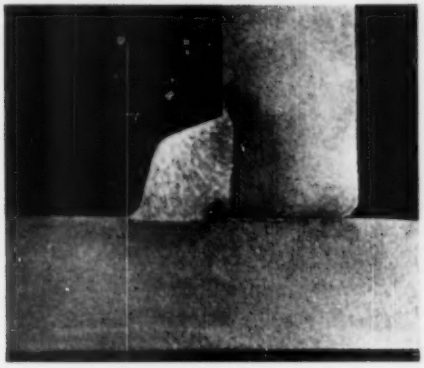


Fig. 36. Horizontal-vertical fillet weld. Excessive convexity and lack of root penetration due to too low a current.

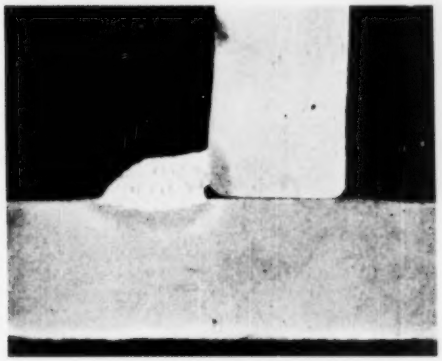


Fig. 37. Horizontal-vertical fillet weld. Uneven leg length; also shows lack of root penetration, and slag inclusion.

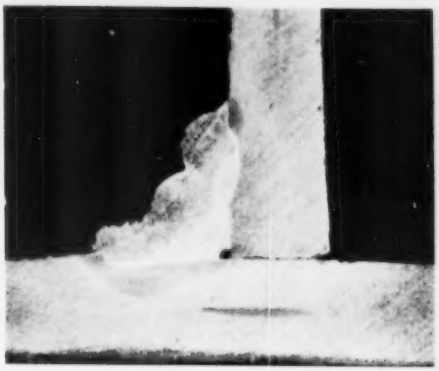


Fig. 38. Horizontal-vertical fillet weld. Uneven contour.

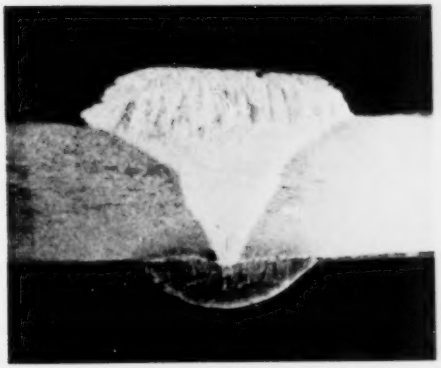


Fig. 39. Single vee butt weld. Overlap with excessive reinforcement and sealing run.

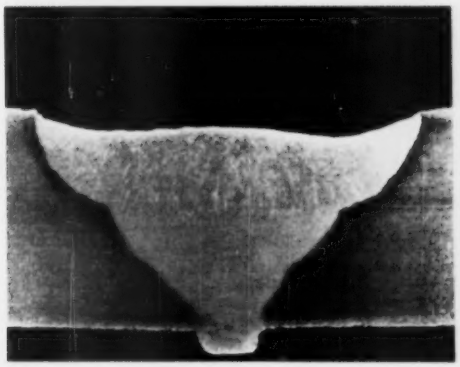


Fig. 40. Single vee butt weld. Weld face insufficiently built up (lack of reinforcement).

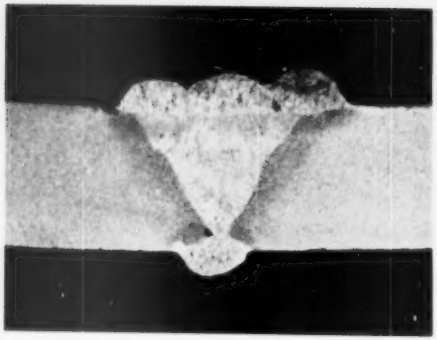


Fig. 41. Single vee butt weld. Irregular contour; also shows lack of penetration and small slag inclusion.

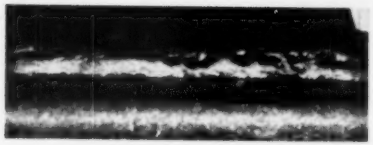


Fig. 42. Surface porosity in fillet weld on steel having high sulphur content.

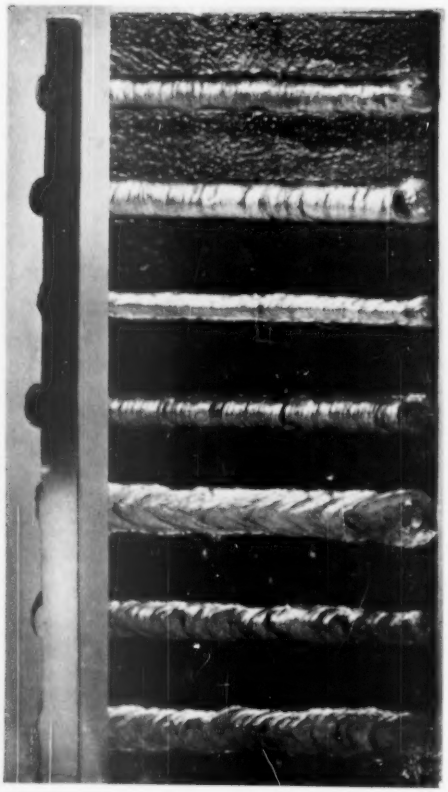


Fig. 43. Effect of welding procedure on appearance of weld bead

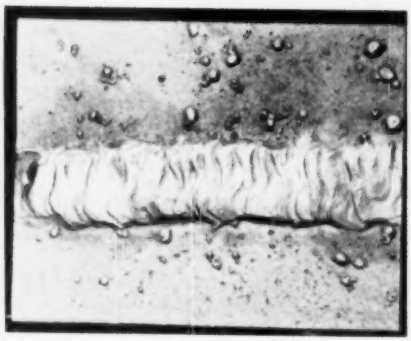


Fig. 44. Spatter.

Description

Incorrect weld size refers to undersize fillet welds, or fillet welds of variable size, as measured by the minimum leg length.

The faults associated with incorrect size and profile in fillet welds are, excessive convexity or concavity, irregularity of the weld face, and unequal leg lengths. (Figs. 35 to 38.)

In butt welds incorrect profile refers to lack of reinforcement, excessive reinforcement or irregularity of the weld deposit. Lack of reinforcement applies to a condition where the weld face lies below the surface of the parent plate, and excessive reinforcement to a condition where weld metal is deposited substantially in excess of the reinforcement required. (Figs. 39 to 41.)

Cause and Prevention

Welds of incorrect size, or unsatisfactory profile, generally arise from the use of a faulty welding technique.

Excessive convexity or concavity of the weld face may, in certain cases, be due to the welding characteristics of the electrode. These faults are more generally attributable, however, to the use of incorrect welding current, convexity being associated with low current and concavity with high current. The welding position is also a contributory factor in each case.

Fillet welds of unequal leg lengths are generally due to faulty manipulation of the electrode or incorrect positioning of the workpiece when welding in the downhand (i.e. tilted) position. Normally it is difficult to deposit large single run fillet welds of consistent leg length in the horizontal-vertical position since they tend to sag at the base. Welds of more than $\frac{5}{16}$ inch in size should be deposited in more than one run unless they can be made in the downhand position. Undersize fillet welds will be produced if, due to bad fitting up of the parts, the effective leg length is reduced by excessive root gaps.

Excessive reinforcement or lack of reinforcement in butt welds are due to the use of an incorrect welding procedure and should not arise if the joint preparation, electrode size and welding current, the number of runs to be made, and the welding speed, or length of run per electrode are correctly specific and followed.

Effect on Strength

Excessive concavity and unequal leg lengths reduce the throat thickness of fillet welds and hence will also reduce the ultimate strength of the welded joint. Excessively convex fillet welds may be of equivalent static strength to standard welds. The welding conditions which tend to produce fillets of this shape, however, also tend to give rise to such faults as lack of penetration and lack of fusion which, if present, will affect the strength of the weld considerably. Excessive convexity may also be associated with overlapping at the toes of a weld and, due to the resulting notch effect and stress concentration, the fatigue strength of a joint will be seriously reduced where these faults are present.

Both lack of reinforcement and excessive reinforcement will reduce fatigue strength. Lack of reinforcement in butt welds may also prevent the joint from developing the full strength of the parent plate under static loading.

Correction

Excessive concavity and unequal leg lengths in fillet welds can be rectified by adding further weld metal. To correct excessive convexity it is necessary to chip away the excess weld metal.

Excessive reinforcement in butt welds may be rectified by removing the excess metal. Lack of reinforcement can be corrected by adding further weld metal.

In correcting these faults, care should be taken that, prior to rewelding, the joint is thoroughly deslagged and is in a clean condition.

(x) *Unsatisfactory Surface Appearance* *

Description

The term "unsatisfactory surface appearance" embraces a number of faulty conditions of the weld surface as distinct from "incorrect weld size and profile" covered in the preceding section. Such conditions are, non-uniform surface ripples, surface porosity (Fig. 42) (or "pock marks"), visible included slag, faulty junction where welds are restarted and end craters.

Cause and Prevention

The formation of rough or irregular weld surfaces is due, mainly, to the use of incorrect welding technique, although in certain cases the welding characteristics of the electrode may affect the surface appearance of a weld. In judging the appearance of a weld, due regard must be paid to the welding position in which it was made.

Fig. 43 illustrates several welds deposited under varying conditions, showing the effects of variations in welding procedure.

Accessibility of joints is an important factor and the position of all welds in a structure should allow the operator adequate manipulation of the electrode.

Effect on Strength

Under fatigue loading conditions such defects may seriously affect the endurance strength of a joint since they form local "stress raisers" and provide sources for potential fatigue cracks. The static strength of a welded joint will not, in general, however, be adversely affected by surface roughness, or by dispersed surface porosity or visible slag.

Correction

Surface roughness, visible slag or surface porosity can be rectified by removing the faulty weld deposit, and by rewelding.

(xi) *Spatter*

Definition: Unintentional deposits of filler metal on the surface of a parent plate or of a weld in the form of small globules.

Description

During the deposition of a weld, small globular deposits of metal from the electrode may be scattered over the surface of the weld and adjacent parent metal and in most cases these adhere strongly. The main objection to excessive spatter is the waste of useful material and the cost of removal. (Fig. 44 shows this fault.)

Cause and Prevention

Spatter is associated mainly with the use of excessive welding current, although in some cases the welding characteristics of the electrode, or dampness of the electrode covering may give rise to this condition. Frequent interruptions of the arc, when welding, may also tend to cause spatter and should be avoided as far as possible.

Effect on Strength

Spatter has no measurable effect on the strength of a welded joint.

Correction

The fault may be rectified by chipping and wire-brushing the spatter deposit from the surface of the plate.

* Note.—No definition of unsatisfactory surface appearance is given since the term covers several conditions. Reference should be made to the description of the various faults included above.

ACKNOWLEDGMENTS

The various illustrations of weld faults are reproduced by courtesy of the following authorities and companies:—

Figs. 5, 22	Admiralty, Naval Construction Dept., Bath
Fig. 28	G. A. Harvey & Co. (London) Ltd.
Figs. 2, 3, 4, 6, 8, 10, 11, 20, 21, 29, 31, 33 to 39, 41, 44	Murex Welding Processes Ltd.
Figs. 12, 13, 14, 16, 17, 32, 40	G. D. Peters & Co. Ltd.
Figs. 1, 9, 18, 19, 23, 26, 27, 42, 43	Quasi-Arc Co. Ltd.
Fig. 30	Railway Executive (Midland Region)

R.54

A Review of Selected Papers on the Flash and Butt Welding of Light Alloys

By P. M. TEANBY

This Report was first issued to members of the British Welding Research Association in August, 1949, as a confidential document.

1. MACHINES

Due to the low resistivity of the light alloys and the corresponding need for high currents, a large quantity of energy input into a flash or butt weld is necessary, and this involves accuracy in machine control in order to obtain consistent results. One of the most important variables to be controlled is the instant of current cut off at the moment of, or very near to, the start of upset.

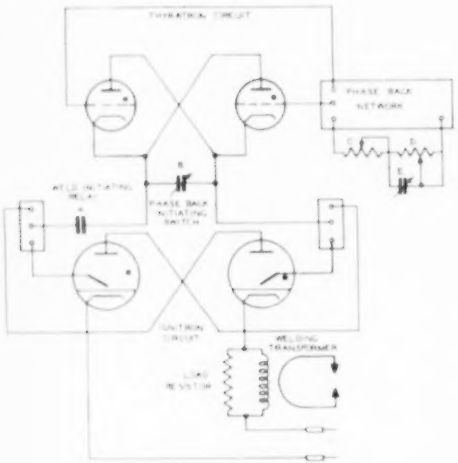


Fig. 1. Current control circuit for flash welding.

The A.C. type of machine, as used for flash welding of steels is, with certain limitations as regards electrical capacity and timers, suitable for flash welding of light alloys (Fig. 1). In view of the high peak currents required for flash welding at the time of upset —between 30,000 and 90,000 amps.—and the consequential increase in the peak loads taken from the mains, three new types have been introduced. The capacity type "stored energy" machine, which uses systems of electrical energy storage, reduces the peak load taken from the mains and makes use of the three-phase supply. A modification of the type of circuit used for spot welding has been introduced by Simmie whereby the gradual discharge of the condenser bank is controlled through a variable resistance during flashing and the controlling circuit is shorted out at the instant of upset, thereby providing the necessary peak surge to complete the weld (see Fig. 2).

The second type of machine is the battery-powered Light Alloy Flash welder.[3] This type has the advantage that it lends itself to the demand of a high continuous current flow rather than a single shot of short duration. Whereas an A.C. machine demands a peak load of 500 K.V.A. single phase at low power factor, a maximum line demand of only 18 K.V.A. is required by a battery operated machine to accomplish a weld of the same cross-sectional area.

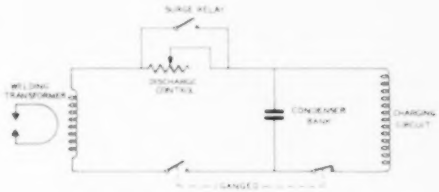


Fig. 2. The simplified Simmie circuit.

The power pack of such a machine consists of 16 cells, each of 8 volts pressure, which are water cooled. The cells are kept charged by being balanced across a three phase supply circuit at approximately 90 per cent. power factor and will deliver a maximum welding current of 38,000 amps. Due to the short duration of the welding cycle required for light alloys such a high drain does not damage the battery plates.

The third type of machine utilises a motor generator power supply connected to a normal flash welding machine through an Ignitron control panel. Such a circuit offers two advantages. It is possible continuously to vary the current delivered to the welding machine by changing the primary voltage. The motor offers a comparatively stable load to the main supply.[5]

TIMERS

The control of time of current flow in flash welding is of a highly critical nature. The most common type of controllers are Ignitrons which are in effect grid controlled rectifiers capable of passing heavy currents, and are themselves controlled by Thyratrons.

Another method of time control is that of tongue contacts operated by cams which commence to operate when the weld cycle is initiated. The cams are so adjusted that they open the weld supply contactors at the moment of upset.

Machine Settings

There are six distinct fundamental variables involved in the flash welding process.

They are:—

1. Flashing speed, time and distance.
2. Variations of speed during flashing by change of cam contour.
3. Power level during flashing.
4. Amount and speed of upset.
5. Magnitude of upset force and current during upset.
6. Timing of current cut-off with respect to upset.

The most important, and also the most critical variable in flash welding is the timing of the current cut off with respect to upset. Best results are obtained when current cut-off and upset occur simultaneously.[5]

The magnitude of upset force and current during upset are also important factors in efficient welding of light alloys. They require higher currents and faster application of forging pressure than steel.

Resistance is the reciprocal of the conductivity of the material involved. In the case of aluminium alloys which are more conductive than steel, less resistance is inherently offered to current flow. For an equivalent cross section, less heating would result than in steel with the same current input.

Aluminium and light alloys in general are from four to five times more susceptible to oxidation at elevated temperatures than steel, thus upset travel must be proportionately faster.

Machines for flash welding must be capable of exerting upwards to 30,000 lbs. of movable platen pressure per square inch of material during the upsetting cycle.[4]

The axial aligning of dies must be within 5 per cent. of tubing wall thickness to prevent telescoping. It is estimated that initial die spacing should be about $\frac{1}{8}$ in. for welding sheet stock or thin walled tubing and will increase to about $\frac{3}{4}$ in. when welding solid bar from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. diameter.

Platen travel during upsetting may be roughly estimated by the following formulæ:—

$\frac{1}{2}$ T + 1/16 in. where T = thickness of material in inches.

And for solids,

$\frac{1}{2}$ D + 1/16 in. where D = diameter of material in inches.

It has been found that cams providing flashing travels of 0·442 in. and 0·266 in. respectively both gave satisfactory results, although the use of the latter cam effected a considerable saving in material burnt away (Fig. 3).

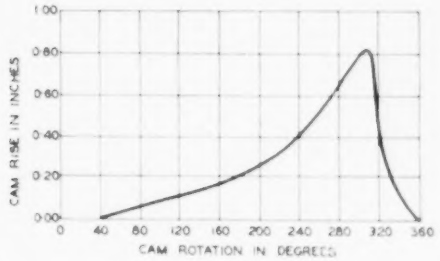


Fig. 3. A typical cam contour.

The high electrical conductivity makes it difficult to ensure satisfactory current distribution, but by increasing the distance between electrode clamps to a maximum consistent with the maintenance of sufficient strength in the material adjacent to the weld, not only is better distribution obtained, but the power required is reduced to a minimum.

An approximate figure for the necessary secondary current is 30,000 amps. p.s.i. The weld period may vary from 0·5 to 10 seconds although weld time is not a governing factor.

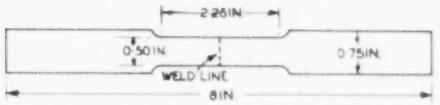


Fig. 4. Standard tensile specimen as used for obtaining results in Table I. (Adapted from Curran and Becker.)

DIES AND CLAMPING

The investigations under review have shown the necessity for efficient clamping of the material when being prepared for welding.

Fixtures designed to give a high clamping pressure over a wide area are necessary to enable even current distribution and to prevent marring the material surface. A further point making a large clamping area necessary is the high thermal conductivity of aluminium and its alloys as compared with those of ferrous materials. See Figs. 5 and 6.

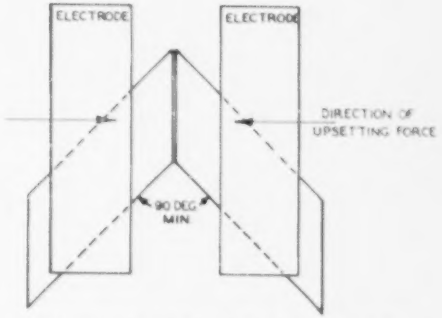


Fig. 5. Satisfactory flash butt welding design for welding at right angles or greater.

Other important features which should be considered when designing tooling for flash butt welding are:—

1. Backing provisions.
2. Ease of insertion in fixture of parts to be welded and their subsequent removal as one piece.
3. Ease of removal of Flash from equipment.
4. Speed of replacements of worn electrodes or electrode inserts.
5. Protection of guides and moving parts of fixtures from flash.

Materials

Some of the light alloys that have been satisfactorily flash or butt welded are:—

14S, 24S, 52S, 53S, 61S and 75S in thickness of 0·125 in., 0·188 in., and 0·250 in.

2S, 3S, 53S and 61S in tubing, extrusion and rolled bar form, 24S-T in the following sizes of strip:—

$\frac{1}{2}$ in. by 0·035 in.
$\frac{1}{2}$ „ „ 0·065 „
$\frac{1}{2}$ „ „ 0·095 „
$\frac{3}{4}$ „ „ 0·083 „
1 „ „ 0·065 „
1 „ „ 0·095 „

also in rod form $\frac{1}{2}$ in., $\frac{3}{4}$ in. and 1 in. diameter 14 S-T.

$\frac{1}{2}$ in. 14 S-T to $\frac{1}{2}$ in. 24 S-T.

For the chemical analysis of alloys see Table IV.

PREPARATION OF MATERIALS FOR WELDING

In most cases no preparation for welding was made, the material being welded in its untouched form as received from the manufacturers.

Della-Vendowa and Reynolds, however, maintain that best results were obtained with square-cut ends and the material etched in 3 per cent. hydrofluoric acid solution prior to welding, although it is probable that other etchants would result in welds of high quality. They point out that if the oxides are not removed from the clamping and abutting surfaces electrical contact in the die area is impaired and the entrapment of oxides in the weld plane frequently occurs.

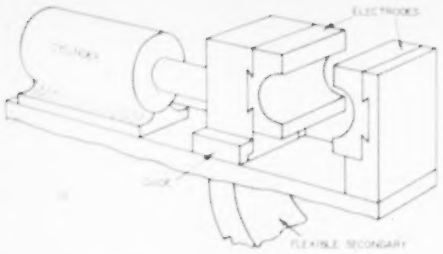


Fig. 6. Horizontal sliding clamp.

Oehler, on the other hand, points out when using a 250 K.V.A. machine welding a section of 4 in. by 5/16 in. of 1¼ sq. in. section that no preparation of the strip was required, and as the welding current reached a peak of 90,000 amps. per sq. in. at the time of upset, flashing was sufficient to ensure squareness automatically.

During the weld a total of 1 in. of material was consumed; approximately 50 per cent. of this was burnt off during the flashing or arcing part of the cycle and the remaining 50 per cent. was extruded as flash metal which was machined off after removal from the machine.

In welding tubing and solid rod it was found that bevelling the ends, as is sometimes practised in ferrous materials, produced low and inconsistent weld strengths.

OXIDE EXCLUSION

Della-Vendowa and Reynolds attempted to prevent or slow down the rapid oxidation of the material at welding temperature by welding in an inert atmosphere.

Argon and helium gases were used, they were dried prior to passing over the welding surfaces by being passed through anhydrous magnesium perchlorate. This attempt failed to improve the weld quality over that obtained in a normal atmosphere.

RESULTS OBTAINED

Hardness

Hardness surveys[1] indicate that most of the alloys are work hardenable. In a survey taken across the weld in the T temper material, it was found that the weld zone was harder than the parent sheet. Since the alloys age harden at room temperature it is probable that a combination of work hardening and re-ageing after solution during the welding cycle takes place. At a distance of 0·12 ins. either side of the weld line there was an area which was softer than the parent sheet. The material in this region was apparently at a temperature sufficiently high for overageing to take place without re-solution, and at the same time did not receive sufficient cold work to compensate for this softening. It is to be expected that this soft zone would be responsible for lowering joint efficiency.

In the case of 53S and 61S it has been shown[1] that these alloys are also work hardenable. The hardness in the welded zone of the hardened alloys is not appreciably different from the hardness of the parent sheet, indicating that the work hardening during the upset cycle was just enough to overcome the softening produced during the welding cycle. Since both these alloys are aged at about 300 deg. F. it is possible that the hardness and strength of the weld zone might further be increased by ageing treatment at that temperature.

The hardness measurements indicate that the production of high strength welds in the hardened tempers requires control of two important phenomena in addition of the elimination of oxide from the weld. The effects of overageing must be kept to a minimum while at the same time the maximum effect of work hardening must be obtained. The final weld strength is dependent on the combined but opposite effects of these phenomena which are in turn a complicated function of the variables associated with the flash welding process.

The best results in solid rod were obtained when the butt welding technique was used. The flat ends of the rod were butted together under an initial pressure before current flow was initiated. The normal weld cycle was then allowed to continue without the occurrence of flashing. This procedure almost entirely eliminated weld zone inclusions in solid rod but could not be used for tubing, due to insufficient rigidity of the tubing wall (Tables I and II).

REFERENCES

1. Oehler, L. A. "Coils for Atom Smashers," *The Welding Engineer*. (Feb. 1948.)
2. Hinxman, H. "Welding Aluminium," *Sheet Metal Industries* (Sept. 1939.)
3. Curran, R. M., and Becker, R. C. "The Flash Welding of Structural Aluminium Alloys," *Welding Research Council Supplement* (Nov. 1947).
4. Close, G. C. "Flash Welding Aluminium," *Light Metal Age (U.S.A.)* (Feb. 1946.)
5. Hess, W. F., and Winsor, E. J., "The Flash Welding of Alclad 24S-T Aluminium Alloy in the 0·064 in. Thickness," *Welding Research Council Supplement* (Jan. 1946.)
6. Della-Vendowa, R., and Reynolds, E. A. "Progress Report on the Flash Welding of High Strength Aluminium Alloys," *Welding Research Council Supplement* (Feb. 1947).
7. "Modern Machines and Methods for Slow Butt Welding," *Sheet Metal Industries* (Jan. 1941).
8. "Battery Powered Aluminium Flash Welder," *The Iron Age* (Dec. 26th, 1946).

Table III. Illustrating the Effect of Flashing Velocity on Secondary Voltage and Tensile Strength

Alloy	Flashing Velocity	Secondary Voltage	Joint Efficiency Per cent.
14 S-T	0·32 in./sec.	19·6	90·0
14 S-T	0·06 in./sec.	7·35	88·0
53 S-T	0·26 in./sec.	17·9	99·0
53 S-T	0·06 in./sec.	7·35	92·5
61 S-T	0·30 in./sec.	17·9	94·6
61 S-T	0·06 in./sec.	7·35	84·1

Table I. Summary of Flash Welding Conditions of Aluminium Alloys

Alloy	Thickness in inches	Flashing Travel (ins.)	Upset Travel (ins.)	Flashing Time (secs.)	Open Circuit Secondary V	Upset Current Duration	Initial Contact (amps.)	Flashing (amps.)	Upset (amps.)	As Welded Strength	As Welded C.V. per cent.	As Welded Joint Effic.	Machined Strength	Machined C.V. per cent.	Machined Joint Effic.
14 S-O	0·125	0·45	0·30	1·1	10·3	16·0	28,400	24,100	21,300	27,650	2·0	95·5	27,500	1·3	94·8
	0·188	0·40	0·67	1·4	10·3	16·0	27,200	20,400	20,400	29,000	0·8	100·0			
	0·250	0·56	0·78	1·4	17·9	17·0	34,700	29,500	26,000	29,100	0·9	100·0			
14 S-T	0·125	0·43	0·35	1·1	10·3	6·0	27,000	21,600	18,900	64,700	5·8	90·6			
	0·188	0·40	0·67	1·4	10·3	15·0	27,200	20,400	20,400	69,600	1·0	97·5	62,800	2·1	88·0
	0·250	0·38	0·71	1·2	17·9	17·0	36,100	30,700	27,100	68,630	2·9	96·1	64,300	—	90·0
24 S-O	0·125	0·35	0·28	1·1	10·3	16·0	27,100	23,000	20,300	30,900	1·7	100·0			
	0·188	0·26	0·78	1·4	14·4	15·0	31,500	26,800	26,800	29,960	0·5	100·0			
	0·250	0·49	0·67	1·5	17·9	17·0	36,500	31,000	27,400	27,700	—	86·6			
24 S-T	0·125	0·46	0·56	1·4	10·3	15·0	25,600	19,200	19,200	68,000	1·0	96·1	65,600	5·5	92·6
	0·188	0·26	0·78	1·4	14·4	15·0	31·400	26,700	26,700	68,000	—	96·1			
	0·250	0·35	0·72	1·2	17·9	24·5	38,600	32,800	29,000	65,950	2·0	93·1	68,500	—	96·6
52 S-O	0·125	0·59	0·36	1·85	11·8	5·3	24,700	18,500	16,000	29,000	1·0	100·0	28,420	1·0	100·0
	0·188	0·69	0·57	1·00	16·9	25·0	35,500	35,500	26,600	26,770	4·9	89·6	26,480	3·5	88·7
	0·250	0·44	0·67	1·3	17·9	25·0	38,100	38,100	30,500	26,900	2·7	90·1	27,600	—	92·5
52 S-½H	0·125	0·54	0·41	1·85	11·8	5·0	23,400	17,600	15,200	37,870	0·7	100·0	32,690	1·4	88·7
	0·188	0·40	0·57	1·29	15·0	5·0	28,600	22,900	17,200	38,930	1·0	100·0	36,720	0·9	99·6
	0·250	0·34	0·72	1·28	17·9	17·5	40,100	40,100	32,900	36,710	0·7	99·5	35,460	—	96·2
53 S-O	0·125	0·49	0·59	1·4	11·8	15·0	27,800	20,800	20,800	15,740	0·4	97·4			
	0·188	0·37	0·64	1·4	13·4	15·0	29,800	26,350	26,350	16,170	0·6	100·0			
	0·250	0·62	0·94	1·5	17·9	17·5	34,200	29,100	25,700	15,800	—	97·8			
53 S-T	0·125	0·46	0·56	1·4	11·8	15·0	27,200	20,400	20,400	41,400	—	100·0			
	0·188	0·37	0·65	1·4	13·4	15·0	26,600	19,900	19,900	41,200	0·5	100·0			
	0·250	0·36	0·80	1·37	17·9	24·5	35,700	30,400	26,800	38,250	0·7	96·9	39,100	—	99·0
61 S-O	0·125	0·45	0·55	1·4	11·8	15·0	26,800	20,100	20,100	19,000	0·8	100·0			
	0·188	0·37	0·66	1·4	13·4	15·0	26,700	20,000	20,000	19,350	—	100·0			
	0·250	0·54	0·62	1·5	17·9	17·0	36,500	31,000	27,300	18,400	—	97·0			
61 S-T	0·125	0·48	0·58	1·4	11·8	15·0	26,950	20,200	20,200	47,450	1·2	99·0			
	0·188	0·36	0·67	1·4	13·4	15·0	26,800	20,100	20,100	48,560	2·1	100·0			
	0·250	0·37	0·79	1·23	17·9	24·5	36,400	30,900	27,300	47,670	1·7	99·3	45,400	—	94·6
75 S-O	0·125	0·54	0·41	1·85	11·8	4·5	23,400	17,600	15,200	34,480	0·8	100·0	34,840	0·8	100·0
	0·188	0·41	0·56	1·30	15·0	5·0	29,500	23,600	17,700	33,200	1·7	94·6	32,510	0·9	92·5
	0·250	0·35	0·73	1·3	17·9	24·5	41,900	41,900	33,500	31,030	7·2	88·3	34,620	—	98·5
75 S-T	0·125	0·52	0·42	1·85	11·8	5·5	23,400	17,600	15,200	73,450	1·4	92·8	73,790	3·3	93·1
	0·188	0·40	0·55	1·31	15·0	6·0	28,300	22,640	17,000	77,100	1·1	97·2	74,910	1·1	94·4
	0·250	0·41	0·70	1·30	17·9	25·0	40,000	40,000	32,100	75,850	1·3	95·5	72,740	—	91·6

Gaps indicate insufficient specimens to obtain results.

Table II. Summary of Tensile Test Results with Tube and Rod

Material 24 S-T	Sizes Welded (inches)	No. of Specimens	Ultimate Strength P.S.I. Max.	Min.	Average	Parent Metal Strength	Average Joint Efficiency per cent.	Coefficient of Variation Cv per cent.†	Number of Specimens within ± 10 per cent. of Average	Number of Specimens within ± 20 per cent. of Average
Tubing	$\frac{1}{2} \times 0.065$	25	73,900	61,000	69,484	74,400	93·4	5·0	23	25
	$\frac{1}{2} \times 0.095$	25	72,100	48,550	68,164	70,700	96·4	7·0	24	24
	$\frac{3}{4} \times 0.083$	25	72,250	67,800	70,562	72,500	97·3	1·9	25	25
	1×0.065	25	71,900	47,800	65,662	72,900	90·2	9·0	21	23
	1×0.095	25	74,345	66,502	72,695	74,074	98·0	2·0	25	25
Solid Rod	$\frac{1}{2}$ diameter*	18	66,346	58,986	62,872	73,129	86·0	3·8	18	18
	$\frac{3}{4}$ diameter	25	68,884	55,968	65,391	73,129	89·4	6·3	22	25
	1 diameter	25	65,000	45,900	56,952	69,200	81·9	10·0	15	25

* $\frac{1}{2}$ inch diameter 14 S-T to $\frac{1}{2}$ inch diameter 24 S-T.
† The coefficient of variation (Cv) is an inverse measure of consistency. The lower the value the better the consistency.

N.B.—1. External flash completely removed before testing.
2. All specimens allowed to age harden at room temperatures for at least 3 days before testing.
3. $\frac{1}{2} \times 0.035$ and 1 inch solid not satisfactorily welded here due to equipment capacity limitations.

Table IV. Nominal Compositions of Some American Aluminium Alloys

Alcoa Designation	Cu per cent.	Si per cent.	Mn per cent.	Mg per cent.	Zn per cent.	Cr per cent.	British Equivalents Specification Designations	
2S		99 per cent. minimum aluminium					A4D* BSS. 2L17* 2L16* 2L4* L34†	Noral 2S Alcan 2S B.A. C.P. Kynal P10, etc.
3S	—	—	1·2	—	—	—	AW. 3C* DTD. 653* DTD. 213A*	Noral 3S Alcan 3S B.A. 60 Hid 11 Kynal PA. 19
14S	4·4	0·8	0·8	0·4	—	—	DTD. 603B* 646B* AW. 15A† DTD. 364B†	Noral 26S Alcan 26S B.A. 303 Dural S Hid 66 & 01 Kynal C65, C66
52S	—	—	—	2·5	—	0·25	DTD. 634* BSS. L44†	Noral 57S Alcan 57S B.A. 21 B.B. 2 M.G.2, etc.
53S	—	0·7	—	1·3	—	0·25	—	Alcan 55S
61S	0·25	0·6	—	1·0	—	0·25	—	Noral 65S Alcan 65S
75S	1·6	—	—	2·5	5·6	0·30	DTD. 687*‡ DTD. 683†	Noral M75S Alcan 75S Hid RR77 Dural L

* Sheet. † Extrusions. ‡ Clad Sheet.

BRITISH WELDING RESEARCH ASSOCIATION
29 PARK CRESCENT - - - - LONDON, W.1

Publications

The following is a list of publications obtainable from the British Welding Research Association. You may use this list as an order form, indicating your requirements by placing a cross on the line provided by the side of each title.

Ref.	*Author and Title*	*Price*	
	Special Reports		
*R.*1	Baker, J. F., and Roderick, J. W. **Investigation into the behaviour of welded rigid frame structures.** (First interim report.) An experimental investigation of the strength of seven portal frames. Ill. Oct. 1938	3/-	
*R.*2.	Turnbull, J. **Investigation of the welding of ships' structures.** (First interim report.) A description of the testing apparatus. Ill. Jan. 1939	2/-	
*R.*3.	Gardner, E. P. S. **Effective control of strength and soundness of fillet welds by welding procedure limitations and inspection.** Ill. March 1939	2/-	
*R.*4.	West, E. G. **The welding of non-ferrous metals:** a review of published information. Ill. March 1939	3/-	
*R.*5.	Turnbull, J. **Investigation of the welding of ships' structures.** (Second interim report.) Ill. April 1940	2/6	
*R.*6.	Baker, J. F. and Roderick, J. W. **Investigation into the behaviour of welded rigid frame structures.** (Second interim report.) Further tests on beams and portals. Ill. April 1940	2/6	
*R.*7.	West, E. G. **Fluxes for welding aluminium.** Ill. April 1940	2/6	
*R.*10.	Reeve, L. **A summary of reports of investigations on selected types of high tensile steels.** Ill. Oct. 1940	2/6	
*R.*13.	West, E. G. **The gas welding of commercial and super-purity aluminium.** Ill. April 1941	2/6	
*R.*14.	West, E. G. **The fluxing action in the gas welding of aluminium.** Ill. April 1941	2/-	
*R.*15.	Tylecote, R. F. **The spot welding of light alloys:** a review of published information. Ill. April 1941	2/6	
*R.*17.	Dorey, S. F. **Memorandum on the application of welding to pressure vessels.** Oct. 1941	2/-	
*R.*18.	Baker, J. F., and Roderick, J. W. **Investigation into the behaviour of welded rigid frame structures.** (Third interim report.) The behaviour of stanchions bent in single curvature. Ill. July 1942	3/-	
*R.*21.	Turnbull, J. **Investigation of the welding of ships' structures.** (Third interim report.) Ill. 1943	2/6	
*R.*23.	Hanson, D., Cottrell, A. H., Wheeler, J. A., Winterton, K., and Crowther, P. D. **Researches in alloy steel welding.** July 1944	7/6	

R.24. Roderick, J. W., with foreword by Baker, J. F.
Investigation into the behaviour of welded rigid frame structures. (Fourth interim report.) The behaviour of stanchions bent in single curvature. Ill. Dec. 1945 ... 5/-

R.25. Horne, M. R.
A moment distribution method for rigid frame steel structures loaded beyond the yield point ... 5/-

R.26. Turnbull, J.
Investigation of the welding of ships' structures. (Fourth interim report.) Ill. Jan. 1946 ... 2/6

R.27. Needham, J. C.
The transfer of material temperature and stability in the electric welding arc. A résumé of published information. Ill. Jan. 1946 ... 7/6

R.28. **Argonarc welding:** collected papers presented to the I.M.3 Committee on Fusion Welding of Magnesium-Rich Alloys ... 7/6

R.29. Tylecote, R. F.
Pressure welding of light alloys without fusion. Ill. Jan. 1946 ... 5/-

R.33. Percival, A. L., and Weck, R.
Fatigue tests by the resonance vibration method on four welded H-beams. (First interim report.) ... 5/-

Techniques and Memoranda

T.1. **Technique for the gas welding of rolled aluminium and aluminium alloy castings.** 2nd Ed. Ill. May 1942 ... 2/6

T.2. **The arc welding of high tensile (low alloy) structural steels.** (Metal arc welding.) 2nd Ed. Feb. 1944 ... 9d.

T.5. **Recommendations for oxy-acetylene butt welds in mild steel pressure pipe lines.** Ill. Aug. 1941 ... 2/-

Colour charts ... 2/- extra

T.6. **Technique for the gas welding of copper.** Ill. Feb. 1943 ... 2/6

T.10. **Memorandum on deep penetration butt welding with semi-automatic welder.** Ill. Feb. 1943 ... Free

T.12. **Memorandum of manual welding of butt welds in the downhand position, and with welded-on backing bars** ... Free

T.13a. **Recommended technique for making fillet welds in the downhand, vertical and overhead positions.** Ill. Revised March 1945 ... Free

T.14. **The control of welding.** Papers contributed to a Symposium organised by the Scottish Branch of the Institute of Welding, Glasgow, 14th March 1944. Oct. 1944 ... Free

T.15. **Recommended technique for making butt welds in mild steel plating in the downhand position with overhead back runs and in the vertical and horizontal positions.** Ill. Nov. 1945 ... Free

T.16. **Technique for the gas welding of magnesium alloys.** May 1946 ... 2/-

T.17. **Arc welded structural steelwork. (1) stanchions, bases, caps and joints.** March 1946 ... 9d.

T.18. **Recommendations for the design of arc welded mild steel machinery constructions** ... 2/-

T.19. **The testing of light alloy fusion welds** ... 2/-

T.20. **Heat treatment of welded constructions in mild steel** ... 1/6

T.21. **Recommended practice for the spot welding of low carbon mild steel sheet** ... 1/6

Reprints

P.1. Dearden, J., and O'Neill, Hugh
Guide to the selection and welding of low alloy structural steels ... 2/-

P.2. **Training syllabus for shipyard welders** ... 1/6

P.3. Reeve, I.
Influence of sulphur and phosphorous on weldability of mild steel ...

P.7. Ball, J. G.
The Metallurgical Laboratories of the B.W.R.A. ... Free

P.8. Ball, J. G.
Recent progress in the metallurgy of the welding of non-ferrous metals ... 5/-

*P.*10.	**Research at Abington Hall**	Free
*P.*11.	Cottrell, C. L. M. **A multi-point furnace control panel**	Free
*P.*12.	Weck, R. **Present position of residual stresses in welded structures**	1/6
*P.*13.	Hipperson, A. J., and Watson, T. **Recommended machine settings for resistance welding in mass production**	Free
*P.*14.	Finniecome, J. R., M.Eng., M.I.Mech.E. **Thrusts and stresses in two-dimensional pipe expansion bends**	Free
*P.*15.	Baker, J. F., O.B.E., M.A., Sc.D., D.Sc., M.I.C.E. **A review of recent investigations into the behaviour of steel frames in the plastic range**	Free
*P.*17.	Moore, E. C., A.M.I., Mech.E. **Economies of Castings and Weldings**	1/-
*P.*18.	Atkins, W. S., B.Sc., Assoc. M. Inst. C.E. **Survey of the use of welding in structures**	1/-
*P.*19.	S. M. Reisser, B.Sc. (Eng.), Assoc.M.Inst.C.E., M.I.Struct.E., M.Inst.W. **Survey of the use of welding in structures**	1/-
*P.*20.	**Economy of steel and cast iron by welding**	1/-
*P.*21.	Statements by Ashorne Hill Conference Rapporteurs. **Welding as an aid to steel economy**	1/-
*P.*24.	Weck, R. **Stress relieving of welded structures**	Free
*P.*25.	Baker, J. F., O.B.E., M.A., Sc.D., M.I.C.E., M.I.Struct.E. **The Design of Steel Frames**	Free

Welding Research

The following Reports have appeared in WELDING RESEARCH (Journal of the British Welding Research Association). Copies price 5/-.

Vol. 1, No. 1, April 1947	Hipperson, A. J.	**The relationship between welding conditions and the strength and quality of single spot welds in deep drawing quality mild steel in thicknesses from 20 to 13 S.W.G.**
,,		**Arc welded structural steelwork:—(1) Stanchions, bases, caps and joints.** (Reprint of *T.*17)
Vol. 1, No. 5, Dec. 1947	Sparkes, F. R.	**The behaviour of webs of plate girders**
,,		**Instruments for the measurements of the main variables in resistance welding**
Vol. 3, No. 1, Feb. 1949	Tylecote, R. F.	**The pressure butt welding of light alloy bar.** (*R.*42.)
,,	Orton, L. H., and Needham, J. C.	**Short time phenomena in the iron welding arc. Metal bridging and short circuiting of the arc.** (*R.*43.)
Vol. 3, No. 2, April 1949	Koenigsberger, F., Dipl.-Ing., M.I.Mech.E.	**Welding as a means of economising on material and labour in the manufacture of machinery structures.** (*R.*44)
,,	Redshaw, L., M.Eng., M.I.N.A., M.Inst.W.	**Welding in shipbuilding with particular reference to passenger construction.** (*R.*45)
Vol. 3, No. 3, June 1949	Hagan, H. H., M.I.N.A.	**The economic construction of moderate sized all-welded ships.** (*R.*46)
,,	Byrne, B. R., A.Inst.W., A.M.I.Loco.E.	**Welding as applied to railways and rolling stock.** (*R.*47)
,,	Swinnerton, N. W., M.I.Struct.E., M.Inst.W.	**Welding on British Railways—trackwork and structures.** (*R.*48)
,,	Foster, G., B.Sc., A.M.I.Mech.E., M.I.Loco.E., M.Inst.W. (British Railways).	**Welding as an aid to the saving of steel and manpower in railway workshops.** (*R.*49)

Vol. 3, No. 4. Aug. 1949 — Pendleton, J., B.Eng., A.I.M. **Gas welds in aluminium-magnesium alloy sheet.** (*R.*50)

Vol. 3, No. 5. Oct. 1949 — Hipperson, A. J., B.Sc., and Teanby, P. M. **An evaluation of the resistance welding of tin and tin-zinc alloy coated mild steel sheet.** (*R.*51)

Vol. 3, No. 6. Dec. 1949 — Pearson, C. E., M.Met., F.I.M. and Parkins, R.N., B.Sc., L.I.M. **Stress-corrosion cracking in welded steel structures.** (*R.*52)

Duplicated Reports

The following have not been printed but copies in typescript can be supplied:—

I.M.I.8(a) — Harmer, D. J., and Brooks, H. **Strength tests on fusion welds in duralumin-type alloys.** July 1946

I.M.I.9(a) — Marshall, W. K. B. **Welding of some high strength aluminium alloys.** Jan. 1947

I.M.4.10 — Tylecote, R. F. **The pressure welding of light alloy bar without fusion.** Jan. 1946

I.B.4 — **Arc welding of aluminium and its alloys.** A selected bibliography

Miscellaneous

(A few copies of the following reports are also available)

Advisory service on welding memoranda:—

No. 1 — **Memorandum on specifying welds on drawings and control of arc welding procedure**

No. 2 — **Welding of high tensile steels**

No. 3 — **Memorandum on jigs and manipulators for fusion welding**

No. 4 (c) — **Memorandum on the resistance welding process**

No. 6 — **Memorandum on welding for the repair of steel framed shed buildings**

No. 8 — **Memorandum on the inspection and control of quality of spot welds in mild steel**

Examination of arc welds in the shipyard

Application of electric arc welding to ship construction

Kinzel, Augustus B. **Solid phase welding**

Taylor, H. G., Director of Research, B.W.R.A. **Trends in American welding research and practice** — Free

Spot welding of mild steel—Slide rule — 1/6

I.E.1.2 — Baker, J. F. **Plastic design of single bay portal frames.** Sept. 1947 — 5/-

Printed in England by Lawrence Press Ltd., Henry Road, New Barnet, Herts